

EXPERIMENTAL STUDY AND THERMAL CHARACTERIZATION OF PHASE CHANGE COMPOSITE MATERIAL

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ABSTRACT

Phase change materials (PCMs) has applications in many areas of daily life like automotive, aerospace, consumer -related and thermal engineering industries. Continuous effort is made in developing different composite PCMs and improving the performance characteristics of them to use in different applications. The work is aimed towards the analytical and experimental method of determining the thermal conductivity of phase change material and its variation with temperature for different weight ratios of SiO₂ PCM composite. This has been investigated by preparing the SiO₂ PCM composite specimens of 0%, 5%, 10% SiO₂ for normal SiO₂. The specimen prepared is experimentally tested in the apparatus developed. In this setup, the specimen is treated as the composite hollow cylinder containing two copper cylinders and one intermediate PCM cylinder. Heat transfer through this composite cylinder in the radial direction is studied, in turn, the thermal conductivity of the PCM is determined and its variation with temperature is also examined. So an effort is made in developing an apparatus for investigating the thermal conductivity of phase change materials and enhancing the thermal conductivity of PCMs by adding normal and SiO₂ in different weight ratios. Comparison of thermal conductivity for different specimens prepared is made and variation of thermal conductivity with temperature is studied for analyzing the thermal performance of phase change materials.

KEYWORDS: PCM Cylinder, SiO₂, Thermal Performance & Temperature

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INTRODUCTION

Global warming and greenhouse effects can be reduced by active utilization of renewable energy sources. Thermal energy storage plays a key role in the application of renewable energy sources and thus it contributes to the reduction of global CO₂ emissions. Thermal energy storage is commonly based on the sensible- or latent-heat-storage techniques. Latent-heat thermal storage is based on the absorption or release of heat when a storage material is changing phase. The thermal-storage materials suitable for latent-heat storage are called Phase-Change Materials (PCMs).

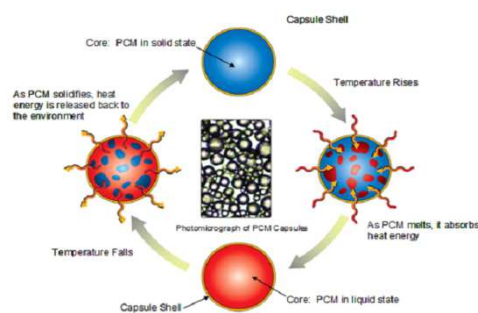


Figure 1

PCMs have considerably higher thermal-energy-storage densities than the sensible-heat-storage materials and they are able to absorb large quantities of energy in a small range of temperatures during the phase change. Phase change materials (PCM) have long been used for thermal energy storage due to a large amount of heat during phase changes, with only small temperature variations. Organic and inorganic materials are two most common groups of PCMs. Most organic PCMs are noncorrosive and chemically stable, and have little or no sub-cooling. But, they have disadvantages of low thermal conductivities.

The thermal properties of PCMS are crucial for the LHS system design. Thermal conductivity is one such property which is of prime importance which decides the performance of PCMS in latent heat storage systems. Due to low thermal conductivity, the performance of PCMs has been hindered. So in this work, to increase the thermal conductivity of low melting substances by adding some metallic and non-metallic materials into the low thermally conductive materials in the weight fractions. So an effort is made in developing an apparatus for investigating the thermal conductivity of phase change materials and enhancing the thermal conductivity of PCMS by adding normal and SiO₂ in different weight ratios. Comparison of thermal conductivity for different specimens prepared is made and variation of thermal conductivity with temperature is studied for analyzing the thermal performance of phase change materials.

LITERATURE REVIEWS

Valan Arasu, et al., (2012) studied paraffin wax it was melted dispersed with SiO₂ that is heated from one side of a square enclosure with dimensions of 25 mm×25 mm is investigated numerically. The stream function, isotherms and liquid–solid interface at different stages of the melting process are presented. The effect of orientation of the heating surfaces of a square cavity and the volumetric concentration of SiO₂ in paraffin wax on the melting performance of the latent heat storage system is analyzed in comparison with pure paraffin wax.

Yibing Cai, et al., (2011) studied the ultrafine composite fibers consisting of lauric acid (LA), polyethylene terephthalate (PET), and silica nanoparticles (nano-SiO₂) were prepared through the materials processing technique of electrospinning as an innovative type of form-stable phase change materials (PCMs). The effects of nano-SiO₂ on morphology, thermal energy storage, thermal stability, and combustion properties of electro spun LA/PET/SiO₂ composite fibers were studied.

C. K. Halford and R. F. Boehm (2007), the paper addresses potential peak air conditioning load shifting strategies using encapsulated phase change materials. The materials being considered here are designed to be installed within the ceiling or wall insulation to assist in delaying the peak air conditioning demand times until later in the evening. To assist in understanding the behavior of this material, an idealized model has been developed which uses the one-dimensional

diffusion equation driven by time-varying temperature functions imposed at the boundaries

N. Soares, J. J. et al, (2013) presents work aims to explore how and where phase change materials (PCMs) are used in passive latent heat thermal energy storage (LHTES) systems, and to present an overview of how these construction solutions are related to building's energy performance. The different types of PCMs and main criteria that govern their selection are reviewed, as well as the main methods to measure PCMs' thermal properties, and the techniques to incorporate PCMs into building elements.

S. Mondal (2007) studied the working principle of PCM and their applications for smart temperature regulated textiles. Different types of phase change materials are introduced. The Concept of thermal comfort, clothing for a cold environment, phase change materials and clothing comfort are discussed.

MATERIALS AND METHODOLOGY

Phase-change materials can be chosen from both organic and inorganic materials. The organic phase change materials melt and freeze repeatedly without a phase-change segregation and crystallize with little or no-super cooling. The organic phase-change materials, e. g. the paraffin's, are compatible with metals without any risk of corrosion. The paraffin's have a rather poor thermal conductivity and they are flammable. The melting point of the alkanes increases with an increased number of carbon atoms. Most PCMs have low thermal conductivity, which prevents them from overcoming problems of rapid load changes in the charging and discharging processes. To overcome this obstacle and to obtain excellent thermal properties, studies have proposed various techniques for enhancing the thermal conductivity of PCMs, such as adding metallic or non-metallic particles with high thermal conductivity. The above-mentioned methods for enhancing the thermal conductivity of PCM involve adding high-conductivity materials to improve the thermal conductivity of PCMs as the most simple and feasible method. Metals have excellent thermal conductivity; therefore, they can be expected to enhance the thermal conductivity of PCMs significantly. However, metal materials oxidize, and their application to PCMs can degenerate and reduces the thermal conductivity of PCMs in the long run. Although adding metal oxides or minerals to PCMs to enhance thermal conductivity is worth considering, the thermal conductivity of such additives must be higher than that of the PCM if they are to enhance the thermal conductivity of PCMs.

Fabricated Experimental Set-Up



Figure 2: Fabricated Experimental Set Up

Conduction of Experiment

The experiment investigates the effects of SiO_2 of 400 mesh and SiO_2 nanopowder on the paraffin to evaluate the heat storage performance. Figure above shows the test apparatus used for the heat conduction performance of composite

PCMs. The 100 g of solid paraffin wax is poured into the copper container. The setup is provided with five thermocouples, out of which three thermo couples are installed in a copper container at different locations within the container, one is provided to measure ambient temperature and remaining one to measure the temperature of heater. The temperature change was recorded by Temperature indicator with channel selector (UNIVERSAL, 6 channels and temperature range up to 0-1200⁰c). The heat input is measured by ammeter and voltmeter readings. Readings are taken at an interval of time of 2 min up to the point that the paraffin wax gets melt during charging. Then set up i. e. container allowed to cooling for discharging. The same is repeated for various volume fractions of silica i. e. SiO₂ of 400 mesh and 100 mesh size added to base PCM.



Figure 3: Images during Different Stages of Conducting Experiments

Readings of Experiment Conducted

Table 1: Pure Paraffin Wax Charging

Time min	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C
0	75	32	32	32	32
2	75	43	36	33	32
4	76	46	38	34	32
6	76	48	40	34	32
8	77	49	40	34	32
10	78	49	42	35	32
12	79	49	43	35	32
14	79	53	45	36	33
16	80	54	46	36	33
18	80	55	47	37	33
20	81	56	49	37	33
22	81	57	50	37	33
24	82	57	51	38	33
26	83	58	53	39	33
28	83	59	54	39	33
30	84	60	54	40	33
32	85	60	55	41	34
34	85	61	56	42	34
36	85	61	56	42	34
38	86	61	56	42	34
40	86	62	56	42	34
42	87	63	57	43	35
44	88	63	58	44	35
46	88	64	58	45	35
48	89	65	60	46	35
50	89	65	60	48	35
52	90	66	62	50	35
54	90	66	63	52	35

Table 1: Contd.,					
56	91	66	64	53	35
58	92	66	65	54	36
60	92	67	65	55	36

Table 2: Paraffin Wax and 5% SiO₂ of 400 Mesh Size Charging

Time min	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C
0	72	33	33	33	33
2	72	37	35	36	33
4	73	40	37	39	33
6	73	41	39	40	33
8	74	43	40	41	33
10	74	44	41	42	33
12	75	45	42	44	34
14	77	47	43	45	35
16	78	49	45	47	35
18	80	51	46	48	35
20	80	52	47	49	35
22	80	53	48	50	36
24	81	54	49	51	36
26	82	55	50	51	37
28	82	56	51	51	37
30	83	57	52	53	37
32	84	58	52	53	38
34	85	59	53	54	38
36	85	60	54	54	38
38	86	61	56	55	39
40	87	61	57	55	40
42	89	62	58	56	41
44	89	62	58	56	41
46	90	63	59	57	42
48	90	64	60	57	42
50	91	64	61	57	42
52	92	65	61	58	42
54	94	65	61	58	44
56	94	66	62	59	44
58	95	67	63	59	45
60	95	67	64	60	45

Table 3: Paraffin Wax and 10 % SiO₂ of 400 Mesh Size Charging

Time Min	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C
0	72	33	33	33	33
2	72	37	35	36	33
4	73	40	37	39	33
6	73	41	39	40	33
8	74	43	40	41	33
10	74	44	41	42	33
12	75	45	42	44	34
14	77	47	43	45	35
16	78	49	45	47	35
18	80	51	46	48	35
20	80	52	47	49	35
22	80	53	48	50	36

Table 3: Contd.,					
24	81	54	49	51	36
26	82	55	50	51	37
28	82	56	51	51	37
30	83	57	52	53	37
32	84	58	52	53	38
34	85	59	53	54	38
36	85	60	54	54	38
38	86	61	56	55	39
40	87	61	57	55	40
42	89	62	58	56	41
44	89	62	58	56	41
46	90	63	59	57	42
48	90	64	60	57	42
50	91	64	61	57	42
52	92	65	61	58	42
54	94	65	61	58	44
56	94	66	62	59	44
58	95	67	63	59	45
60	95	67	64	60	45

RESULTS AND DISCUSSIONS

In this sections, computed thermal conductivity for a various operating temperature of PCM is discussed.

Table 4: Pure Wax Charging

Time min	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C	Temp °C	Thermal Conductivity W/m-K
0	75	32	32	32	32	32.00	0.54
2	75	43	36	33	32	37.33	0.54
4	76	46	38	34	32	39.33	0.527
6	76	48	40	34	32	40.67	0.527
8	77	49	40	34	32	41.00	0.515
10	78	49	42	35	32	42.00	0.504
12	79	49	43	35	32	42.33	0.493
14	79	53	45	36	33	44.67	0.504
16	80	54	46	36	33	45.33	0.493
18	80	55	47	37	33	46.33	0.493
20	81	56	49	37	33	47.33	0.482
22	81	57	50	37	33	48.00	0.482
24	82	57	51	38	33	48.67	0.472
26	83	58	53	39	33	50.00	0.463
28	83	59	54	39	33	50.67	0.463
30	84	60	54	40	33	51.33	0.453
32	85	60	55	41	34	52.00	0.453
34	85	61	56	42	34	53.00	0.453
36	85	61	56	42	34	53.00	0.453
38	86	61	56	42	34	53.00	0.444
40	86	62	56	42	34	53.33	0.444
42	87	63	57	43	35	54.33	0.444
44	88	63	58	44	35	55.00	0.436
46	88	64	58	45	35	55.67	0.436
48	89	65	60	46	35	57.00	0.427
50	89	65	60	48	35	57.67	0.427
52	90	66	62	50	35	59.33	0.419

Table 4: Contd.,							
54	90	66	63	52	35	60.33	0.419
56	91	66	64	53	35	61.00	0.412
58	92	66	65	54	36	61.67	0.412
60	92	67	65	55	36	62.33	0.412

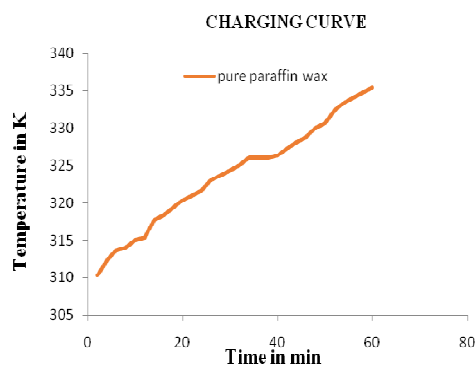


Figure 4: Charging Curve of Pure Wax

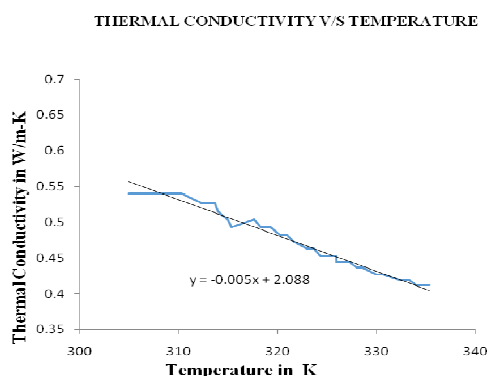


Figure 5: Thermal Conductivity v/s Temperature

The above graph shows the relationship between thermal conductivity and temperature for pure paraffin wax. From the graph, it is seen that, as the temperature increases thermal conductivity decreases. For the temperature range of 305 K to 335.33 K, thermal conductivity decreases 0.54 W/mK to 0.412 W/mK. Hence thermal conductivity is the function of temperature.

Table 5: Charging Paraffin Wax and 10 % SiO₂ of 400 Mesh Size

Time min	T1°C	T2°C	T3°C	T4°C	T5°C	Thermal Conductivity W/m-K	Temp°C
0	70	33	33	33	32	0.63	33.00
2	70	39	37	36	32	0.613	37.33
4	73	44	42	40	33	0.582	42.00
6	74	49	46	42	34	0.582	45.67
8	74	52	49	47	33	0.567	49.33
10	75	55	48	49	33	0.553	50.67
12	76	56	49	50	34	0.553	51.67
14	78	56	49	50	35	0.54	51.67
16	79	57	51	51	35	0.527	53.00
18	79	58	51	52	35	0.527	53.67
20	80	59	52	52	36	0.527	54.33

Table 5: Contd.,							
22	81	60	53	53	37	0.527	55.33
24	82	60	54	54	38	0.527	56.00
26	82	60	54	54	38	0.527	56.00
28	82	61	55	55	38	0.527	57.00
30	83	62	55	55	38	0.515	57.33
32	83	62	55	55	38	0.515	57.33
34	84	63	55	55	39	0.515	57.67
36	84	62	56	55	39	0.515	57.67
38	85	62	57	56	40	0.515	58.33
40	86	64	57	56	41	0.515	59.00
42	86	64	58	56	41	0.515	59.33
44	86	65	59	57	42	0.527	60.33
46	87	66	60	58	41	0.504	61.33
48	88	67	61	60	42	0.504	62.67
50	89	67	62	61	43	0.504	63.33
52	90	68	64	63	44	0.504	65.00
54	91	69	66	65	45	0.504	66.67
56	92	69	68	67	46	0.504	68.00
58	92	70	69	68	47	0.515	69.00
60	92	71	69	69	48	0.527	69.67

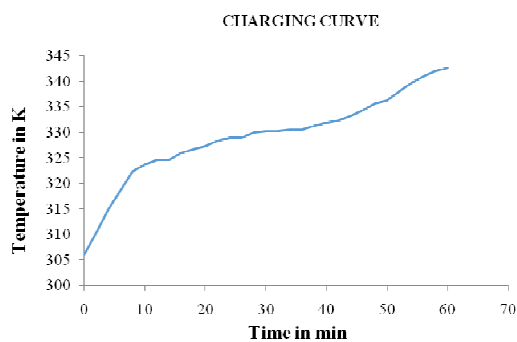


Figure 6

Above graph shows charging curve of pure paraffin wax and 10% SiO₂ of size 400 mesh it shows the variation of the temperature of paraffin wax with time. This graph shows the time required to raise the temperature of paraffin wax to a particular temperature i. e. to store thermal energy.

Table 6: Paraffin Wax and 5% SiO₂ of Size 400 Mesh Size Charging

Time min	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C	Temp °C	Thermal Conductivity W/m-K
0	72	33	33	33	33	33.00	0.597
2	72	37	35	36	33	36.00	0.597
4	73	40	37	39	33	38.67	0.582
6	73	41	39	40	33	40.00	0.582
8	74	43	40	41	33	41.33	0.567
10	74	44	41	42	33	42.33	0.567
12	75	45	42	44	34	43.67	0.567
14	77	47	43	45	35	45.00	0.553
16	78	49	45	47	35	47.00	0.54
18	80	51	46	48	35	48.33	0.515
20	80	52	47	49	35	49.33	0.515
22	80	53	48	50	36	50.33	0.527

Table 6: Contd.,							
24	81	54	49	51	36	51.33	0.515
26	82	55	50	51	37	52.00	0.515
28	82	56	51	51	37	52.67	0.515
30	83	57	52	53	37	54.00	0.504
32	84	58	52	53	38	54.33	0.504
34	85	59	53	54	38	55.33	0.493
36	85	60	54	54	38	56.00	0.493
38	86	61	56	55	39	57.33	0.493
40	87	61	57	55	40	57.67	0.493
42	89	62	58	56	41	58.67	0.482
44	89	62	58	56	41	58.67	0.482
46	90	63	59	57	42	59.67	0.482
48	90	64	60	57	42	60.33	0.482
50	91	64	61	57	42	60.67	0.472
52	92	65	61	58	42	61.33	0.463
54	94	65	61	58	44	61.33	0.463
56	94	66	62	59	44	62.33	0.463
58	95	67	63	59	45	63.00	0.463
60	95	67	64	60	45	63.67	0.463

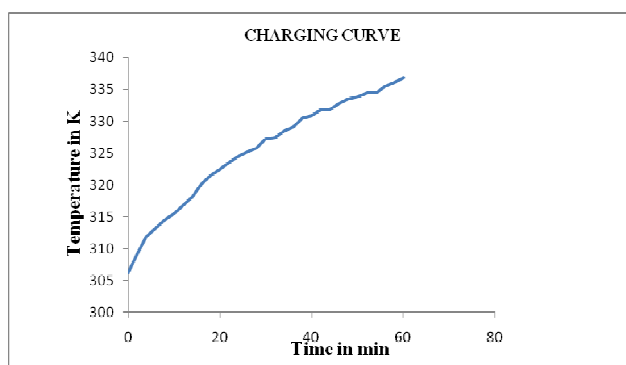


Figure 7: Charging of Paraffin Wax and 5% Silica of 400 Meshes

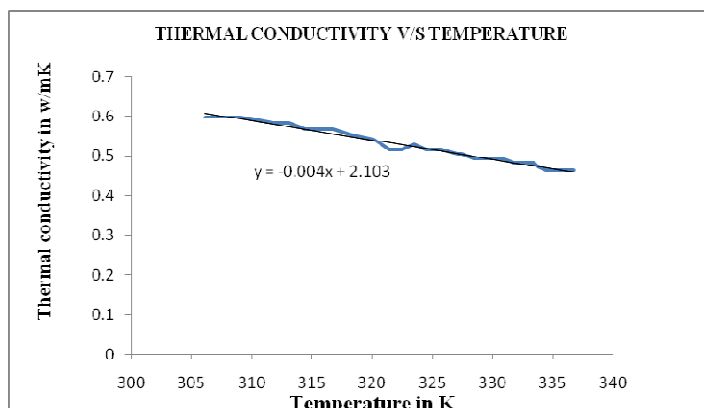


Figure 8: Thermal Conductivity Curve of Paraffin Wax and 5% Silica of 400 Mesh Size

The above graph shows the relationship between thermal conductivity and temperature for pure paraffin wax with 5% normal SiO_2 of size 400 mesh. From the graph, it is seen that, as the temperature increases thermal conductivity decreases. For the temperature range of 306 K to 336.67 K, thermal conductivity decreases 0.597 W/mK to 0.463 W/mK. Hence thermal conductivity is the function of temperature.

CONCLUSIONS

In the experimental study and thermal characterization of nano composite phase change material, the following conclusions are drawn from experimental results.

The thermal conductivity decreases with increase in temperature and upon the addition of SiO₂ to paraffin, the thermal conductivity was significantly enhanced. By the addition of normal SiO₂, the thermal conductivity increases by 10.55% and 13.51% for weight ratios of 5% and 10% respectively. It is seen that addition of nano SiO₂ increases the thermal conductivity by 12.9% and 23.51% for weight ratios of 5% and 10% respectively.

The effect of normal SiO₂ and nano SiO₂ on thermal conductivity of PCMs are plotted on the graphs. The results show that nano SiO₂ has a significant effect on thermal conductivity of PCMs, which enhances the thermal conductivity of PCMs more than that of normal SiO₂. Also, we derived the equation using curve fitting technique which will give thermal conductivity for temperature variation within the limit.

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